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A PROBE FOR MEASURING TEMPERATURE AND PRESSURE AT THE SAME POINTS IN A GAS STREAM

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16. Abstract

This report presents design features and characteristics of a means for measuring total temperature and total pressure at a single point in a gas stream. A rake that provides five such combination measurements is described. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor and for the flow-angle sensitivity of both the temperature and pressure sensors. Data were obtained over a subsonic Mach number range of 0.3 to 0.9 as well as at a Mach number of 1.4.

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A PROBE FOR MEASURING TEMPERATURE AND PRESSURE AT THE SAME POINTS IN A GAS STREAM

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SUMMARY

This report presents design features and characteristics of a combination sensing probe for measurement of gas-stream total temperature and total pressure at a single point. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor and for the flow-angle sensitivity of both the temperature and pressure sensors. Data were obtained over a subsonic Mach number range of 0.3 to 0.9 as well as at a Mach number of 1.4.

INTRODUCTION

In experimental studies of rotating machinery such as compressors and turbines, total pressure and total temperature are important measurements because they are related to efficiency and losses. In some experiments, both measurements are required at a given axial station. For such an application, the user prefers to make both measurements at the same radial location in the gas stream in order to simplify data processing. This report describes a probe that provides such measurements, that is, one which samples total temperature and total pressure essentially at the same point.

Most of the probe information reported in the literature dealing with multiple measurements has been concerned with the measurements of fluid pressures and flow direction. Bibliographies listing several articles concerning these types of probes are given in references 1 and 2. Examples of probes with temperature sensing elements as well as pressure and flow-direction elements are given in references 3 to 5. Although some of the probes referred to in the literature measure more than a single quantity within a small area, they were not specifically designed to make multiple measurements at the same point in the fluid stream.

This report describes the probe and presents flow characteristics over a range of subsonic Mach numbers ($0.3 \leq M \leq 0.9$) as well as for $M = 1.4$. Reynolds numbers ranged from 2×10^4 to 3×10^5 per centimeter. Gas stagnation temperature was near ambient (300 K).

Although the probe described in this report was developed primarily for use in compressor research, it is applicable wherever the requirement of multiple measurement at a point exists.

PROBE DESIGN AND TESTS

Probe Design

The basic concept of the probe element is to install both a bare-wire thermocouple (0.3-mm-diam. wire) and a total-head tube (1-mm o.d.) inside a small oval-shaped shield tube (about 2.5 by 5 mm) which itself acts partially like a total-head tube. A photograph of a rake of five such elements is shown in figure 1.

A detailed drawing of the probe is shown in figure 2. Features of interest in the drawing are (1) the probe support cross section is in the form of an oval to decrease frontal area, which decreases flow blockage; (2) bleed holes on the sides of each shield, near the base of the thermocouple, are used to allow adequate gas flow past the thermocouple junction and total-pressure tube; (3) the inlets of the oval shields are chamfered to make the probe more insensitive to flow misalinement; and (4) a protection rod is incorporated on the support to aid in preventing shield damage when the probe is withdrawn through its installation port.

Tests

The characteristics of the probe were determined in a small tunnel facility at the Lewis Research Center. This facility uses tunnels with test nozzles having throat sections about 8 centimeters in diameter. The flow in the nozzles and test regions was isentropic within the accuracy of the pressure and temperature measurements. Tests were made in air at near ambient temperature. Dry air was employed for the supersonic tests to avoid condensation shocks in the test region. Most of the testing was done in the subsonic Mach number range. However, some data for the thermocouple recovery correction factor were taken at $M = 1.4$.

Time response measurements were obtained by placing a streamlined shield over the probe in the stream and then heating the elements by passing heated air through the

shield. After a steady-state temperature was reached, the hot-air shield was suddenly retracted by a pneumatic actuator, and a temperature step change was thus imposed on the elements. A more detailed description of the test apparatus and measuring system is given in reference 6.

The flow orientation nomenclature used is shown in figure 3.

RESULTS AND DISCUSSION

Temperature Measurement

Thermocouple recovery correction factor. - When thermocouple probes are used, it is convenient to correct for an aerodynamic recovery error by using a recovery correction factor Δ, expressed as

$$\Delta = \frac{T_t - T_{ind}}{T_t} \tag{1}$$

where T_t is the total temperature and T_{ind} is the indicated thermocouple junction temperature. All temperatures are absolute. In an application in which the junction has responded to the aerodynamic flow and conductive or radiative heat exchange is not present, the quantity T_{ind} is equal to the adiabatic junction temperature, and T_t can be calculated from the indicated junction temperature and the value of Δ:

$$T_t = \frac{T_{ind}}{1 - \Delta} \tag{2a}$$

Since $\Delta << 1$,

$$T_t \approx T_{ind}(1 + \Delta) \tag{2b}$$

The recovery correction factor of a thermocouple probe, in alined flow, varies primarily with stream Mach number, and there is a secondary effect of pressure. The recovery correction factor for alined flow, at a total pressure of 10^5 newtons per square meter (1 bar), will be termed the reference recovery correction factor Δ_o.

The variation of Δ_o with Mach number M for the probe is presented in figure 4. The average value for the elements is indicated by the solid line; the shaded region shows the range of variation of the elements. Such shading is used in the figures in

this report wherever a range of variation is shown.

The dashed portion of the curve is an interpolation to a single measurement made at $M = 1.4$.

The value of Δ_o for this probe is about the same as that of other probes of the same general design (e.g., probe 6 of ref. 7).

The variation of the recovery correction factor with pressure, for alined flow, is shown in figure 5. Conductive heat exchange from the support is the most likely cause of this variation. The pressure effect on this thermocouple design is similar to that of reference 5, which used about the same length-diameter ratio of exposed thermocouple.

The variation of recovery correction factor in yawed and pitched flow is presented in figures 6 and 7. These data show a distinction between the element nearest the tip of the probe support (see fig. 2 for location on rake) and the other elements. The yaw data are not symmetrical about the alined-flow (zero-yaw-angle) axis. At positive yaw, separated flow from the shield flows along the thermocouple wires; and at negative yaw, separated flow from the total-pressure tube influences the flow past the wires. The pitch data (fig. 7) are unsymmetrical only for the tip element.

It should be noted that figures 5 to 7 represent only variations in a small correction (fig. 4) that is itself less than 1 percent and therefore may not always have to be applied.

Thermocouple response time. - Time response tests were run in subsonic flow at a static pressure of 10^5 newtons per square meter (1 bar). A typical response curve for the probe is shown in figure 8. It can be seen that the thermocouple does not act like a perfect first-order system. Initially, there is a rapid response of the thermocouple wire, but then the influence, through conduction, of the slower response of the support becomes apparent. The solid line is the actual probe response, and the dashed curve represents the response that would have been expected if the support temperature were constant. The time constant of the first-order response curve (dashed curve) is 1/4 second, but the actual probe response time to reach 99 percent of the final indication was about 4 seconds.

TOTAL-PRESSURE MEASUREMENT

The variation in indicated total pressure with yaw angle is presented in figure 9, where p_t is the true total pressure, $p_{t,ind}$ is the indicated total pressure, and p_s is the stream static pressure. The figure shows that the probe is insensitive to misalinement to within 1 percent of impact pressure at values of yaw angle β up to 19^o in the negative direction and up to 25^o in the positive direction.

Over the range of pitch angles tested ($\pm 25^o$), the probe indicated true total pressure to within 0.1 percent of impact pressure.

CONCLUDING REMARKS

This report presents the design features and characteristics of a combination sensing probe for measuring total temperature and total pressure essentially at a single point in a gas stream. Experimental data are presented for the aerodynamic recovery and time response of the temperature sensor and for the flow angle sensitivity of the total-pressure sensor. Data were obtained over a subsonic range of Mach number from 0.3 to 0.9 as well as at Mach 1.4.

The data in this report present the test results of a single rake consisting of five sensing elements. Because this represents a limited sample, it is advisable that additional probes built from the drawing (fig. 2) be calibrated to determine any major deviation from the curves presented in this report that may be caused by manufacturing tolerances.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 28, 1972,
764-74.

REFERENCES

1. Folsom, R. G.: Review of the Pitot Tube. Trans. ASME, vol. 78, no. 7, Oct. 1956, pp. 1447-1460.
2. Benedict, R. P.: Pressure and Its Measurement. Electro-Technology, vol. 80, Oct. 1967, pp. 70-90.
3. Tysl, Edward R.; Schwenk, Francis C.; and Watkins, Thomas B.: Experimental Investigation of a Transonic Compressor Rotor with a 1.5-Inch Chord Length and an Aspect Ratio of 3.0. I - Design, Over-All Performance, and Rotating-Stall Characteristics. NACA RM E54L31, 1955.
4. Petrash, Donald A.; Davison, Elmer H.; and Schum, Harold J.: Investigation of Turbines Suitable for Use in a Turbojet Engine with High Compressor Pressure Ratio and Low Compressor-Tip Speed. VIII-Internal Flow Conditions of a Two-Stage Turbine with a Downstream Stator. NACA RM E57I19, 1957.
5. Glawe, George E.; Krause, Lloyd N.; and Dudzinski, Thomas J.: A Small Combination Sensing Probe for Measurement of Temperature, Pressure, and Flow Direction. NASA TN D-4816, 1968.

6. Stickney, Truman M.: Recovery and Time-Response Characteristics of Six Thermocouple Probes in Subsonic and Supersonic Flow. NACA TN 3455, 1955.

7. Glawe, George E.; Simmons, Frederick S.; and Stickney, Truman M.: Radiation and Recovery Corrections and Time Constants of Several Chromel-Alumel Thermocouple Probes in High-Temperature, High-Velocity Gas Streams. NACA TN 3766, 1956.

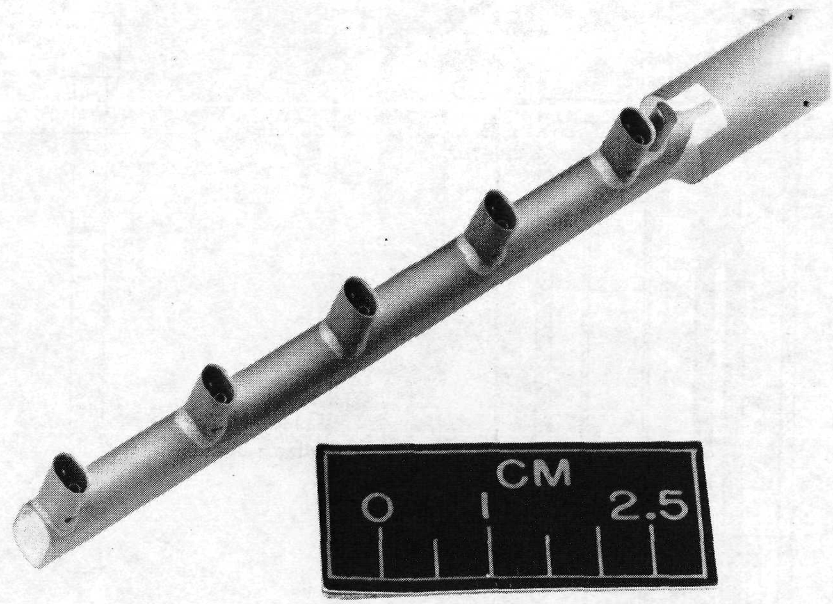

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Figure 1. - Multielement combination sensing probe.

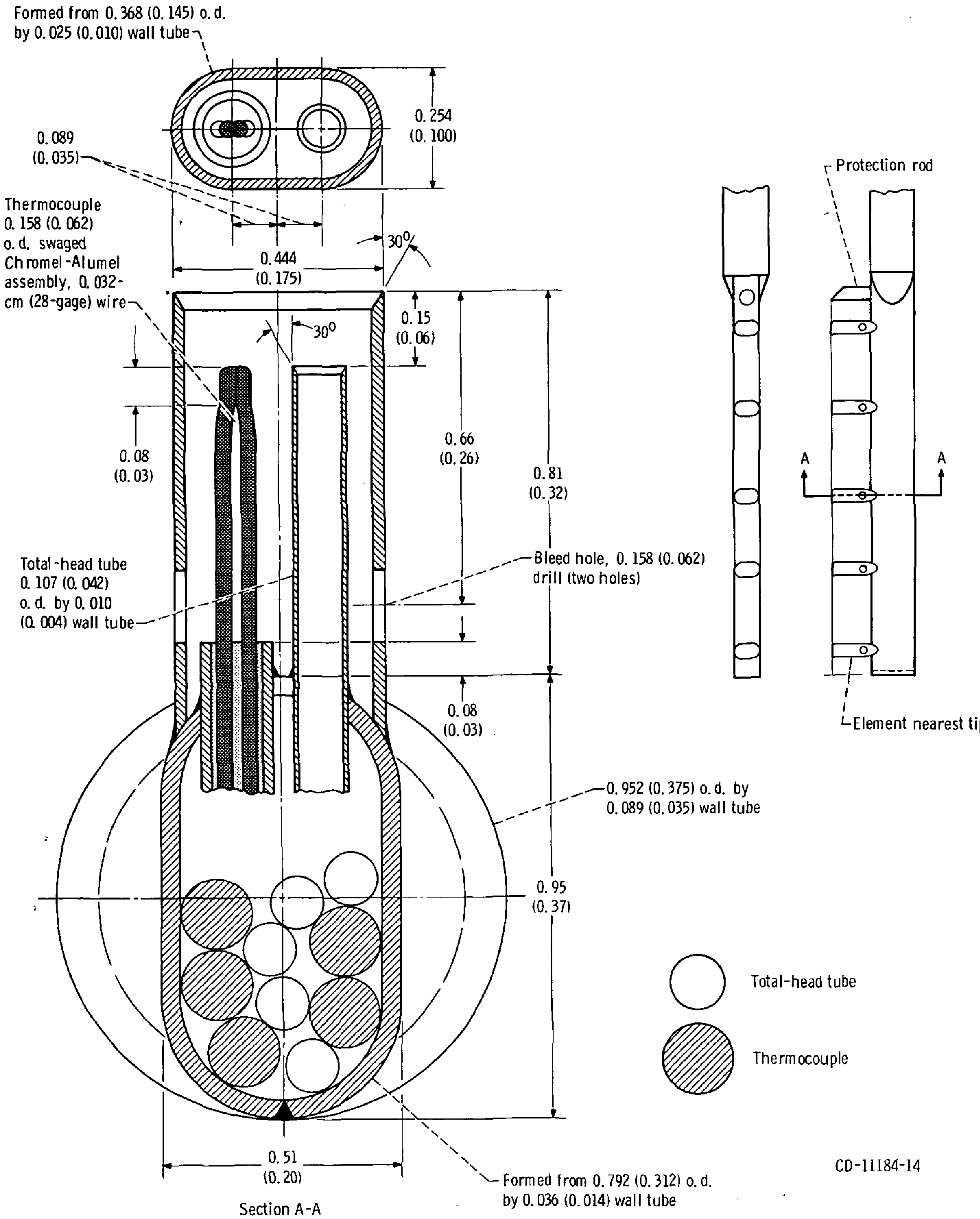

Figure 2. - Probe details. Material, stainless steel; brazed construction. (Linear dimensions are in centimeters (in.).)

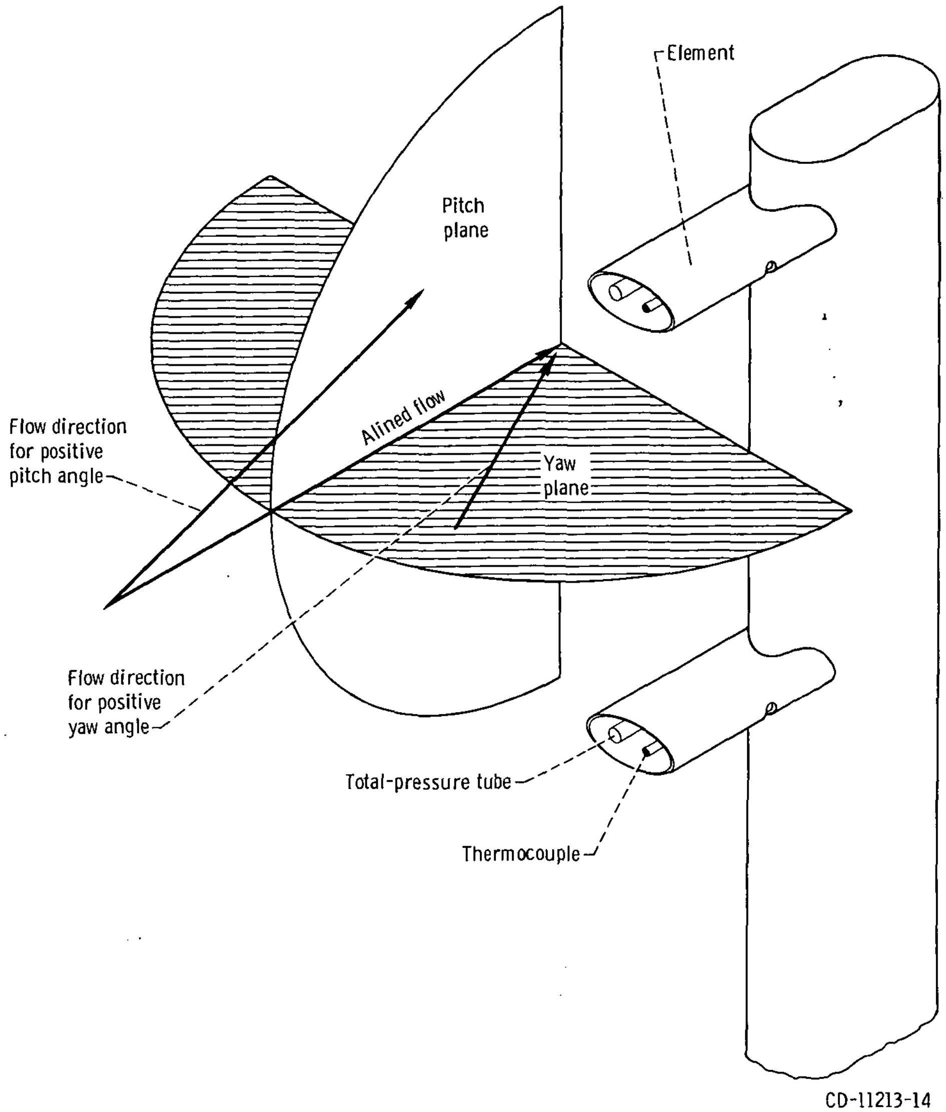

Figure 3. - Flow orientation nomenclature.

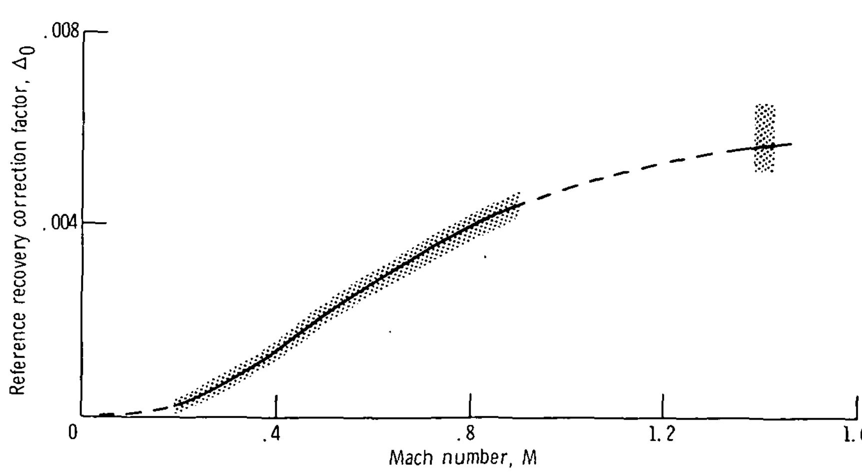

Figure 4. - Variation of reference recovery correction factor with Mach number. Total pressure, 10^5 newtons per square meter (1 bar); alined flow.

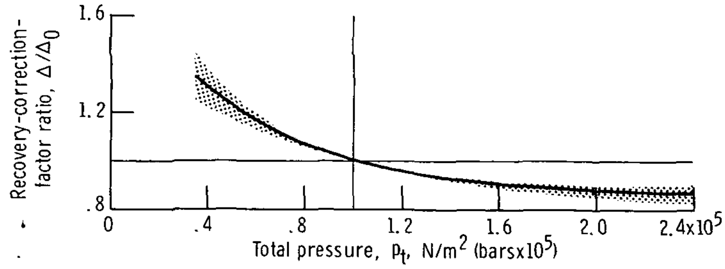

Figure 5. - Variation of recovery-correction-factor ratio with pressure. Recovery correction factor Δ_0 is at 10^5 newtons per square meter (1 bar); alined flow; Mach number, 0.3 to 0.9 and 1.4.

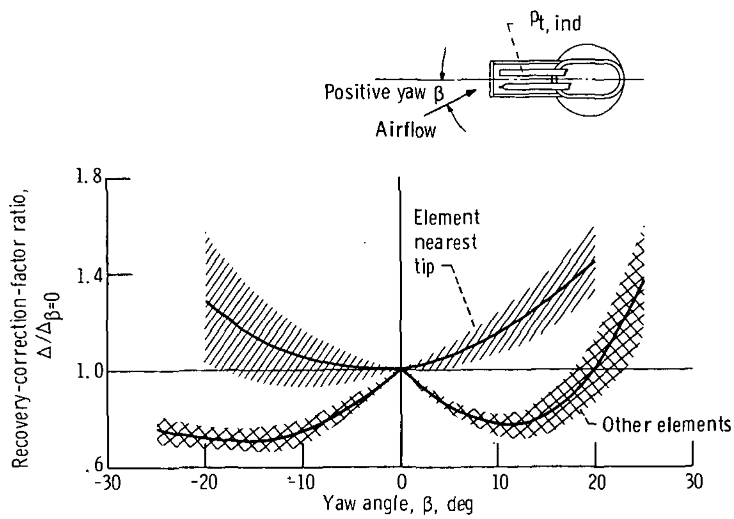

Figure 6. - Variation of recovery-correction-factor ratio with yaw angle. Mach number, 0.3 to 0.9.

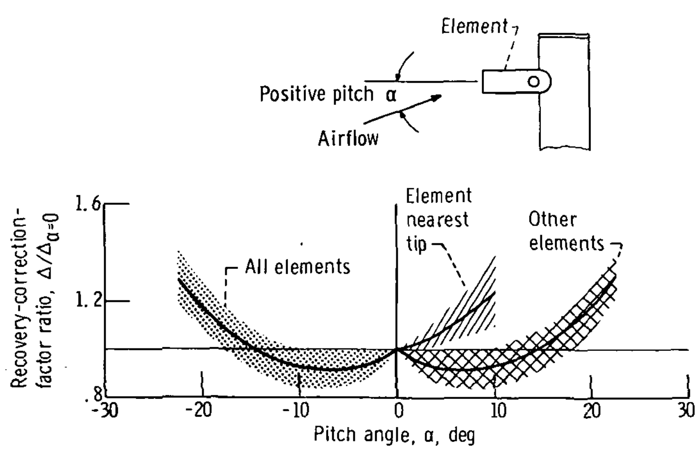

Figure 7. - Variation of recovery-correction-factor ratio with pitch angle. Mach number, 0.3 to 0.9.

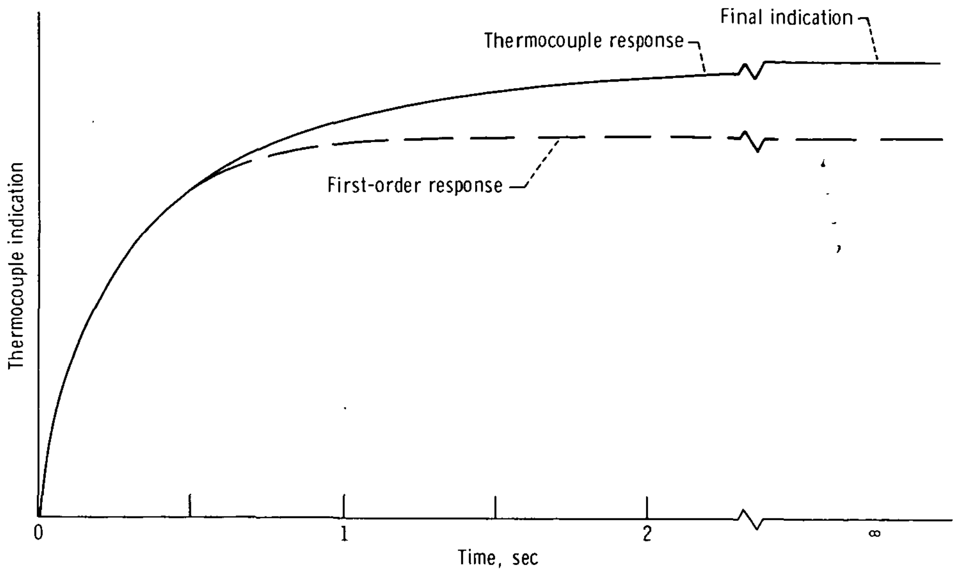

Figure 8. - Typical time response of thermocouple.

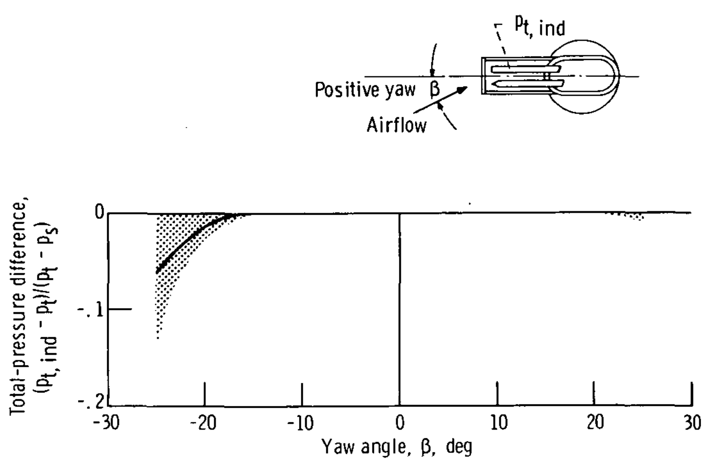

Figure 9. - Variation in total-pressure difference with yaw angle. Mach number, 0.3 to 0.9.

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